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CORRELATIONS BETWEEN MEASUREMENTS AND NUMERICAL SIMULATION RESULTS FOR RING CURRENT PROTONS

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ABSTRACT

ONERA-CERT Spatial Environment Department has developed a physical simulation of the radiation belts dynamics for known magnetospheric conditions called the Salammbô codes. Part of the problem now is concentrated on a good description of the occurrence of these magnetospheric conditions taking into account solar and magnetic variability. Because of several practical and scientific reasons that we will state in the text, we have paid particular attention to the global geomagnetic index Kp through a series of linear correlations with CRRES in-flight measurements of proton fluxes in order to find a possible simple description of storm phenomena. As well, linear correlations between CRRES proton flux measurements (61 keV, 129 keV and 292 keV) and Salammbô 2D results have been made in order to validate the code and to understand the influence of the Kp index that is used as an input parameter in this numerical code.

INTRODUCTION

A good knowledge of the space environment concerning charged particles is important to perform technical, scientific and budgetary assessments about space missions planing and operations, satellite engineering, as well as building and development of materials used for missions, and for scientific analysis of onboard data. Recent measurements have shown that the structure and the intensity of the radiation belts can vary in a hazardous way because they respond to geomagnetic conditions, which vary in association with geomagnetic storms and substorms. Active periods are governed directly by external influences of the solar wind on the magnetosphere. The idea of new internationally recognised models is to put in advances to improve the old ones. One part of the job involves research into one or more parameters able to describe the occurrence of those varying magnetospheric conditions. One simple parameter is proposed here, the geomagnetic index Kp (Menvielle and Berthelier, 1991). The different reasons for its study will be presented first, and then several linear correlations will be shown with in-flight proton CRRES/MEB detector measurements to compare with Salammbô 2D physical code results using this index as an input parameter.

The geomagnetic index Kp is a three hour averaged index. It gives, in a quasi-logarithmic scale from 0 to 9, the global variations of the geomagnetic field. It is deduced from magnetic field measurements of 13 stations located at subauroral (<63°) latitudes. The Kp index is interesting for several practical and scientific reasons. First, ground stations since 1932 have measured this parameter. It provides a database easier and more quickly acquired than any coming from satellites like solar wind parameters. Moreover, such a long period (6 solar cycles from 1932 to nowadays) permits good statistical studies. A three-hour time scale seems sufficient to study the variations of radiation belt electrons with energies higher than 100 keV and protons with energies higher than 10 keV. Finally, subauroral latitudes represent a good situation to study radiation belts, in comparison with auroral or equatorial latitudes of other indices like AE or Dst, because at such latitudes this index can represent a global variation of the magnetosphere, such as storm perturbations in the tail, in the ring current and in the aurora. This index has been already used in the scientific community. First, the Air Force Geophysical Laboratory CRRES models (Brautigam *et al.*, 1992) use mean values of the Ap index over 15 days, strongly linked to Kp. As well, the neural network system of Vampola (1996) uses the Kp index influence over 9 days. Lastly, the equatorial physical model (Boscher *et al.*, 1998) shows a good simulation of the proton radiation belts over long time periods using the Kp index as an input parameter in the model.

LINEAR CORRELATIONS BETWEEN PROTON CODE RESULTS AND CRRES DATA IN FLIGHT MEASUREMENTS

Given two elements X and Y, it is possible to quantify the « degree of fit » to a linear model using the correlation coefficient r that is defined in the interval [-1,1] as the ratio of the covariance of the two elements to the product of their standard deviation. This coefficient is related to how input parameter variations imply output result fluctuations. The absolute level of this coefficient is not really very important, but each value greater than the background level is significant, if we carefully interpret the obtained results.

The Salammbô 2D model takes into account, as sources, the CRAND phenomena (Cosmic Ray Albedo Neutron Decay), and the injections of low energy protons produced on the night side of the magnetosphere by magnetospheric substorms. Radial transport diffusion by electric and magnetic field fluctuations is introduced into the code. Losses are represented by friction with neutral atoms of the exosphere and ionosphere free electrons, by charge exchange with the hydrogen atoms in the exosphere, and by proton precipitation into the ionosphere at all latitudes. The Salammbô 2D code gives proton equatorial fluxes for several energies and L (McIlwain's parameter) locations. In the model, the boundary conditions are fixed at L = 7. They are assumed coming from the plasmasheet and are expressed as a thermal equilibrium with a temperature of 16 keV. They are transported in the code to a trapping boundary calculated with a convective electric field Kp dependent. Then creation of higher energies is related to the transport and acceleration of these particles using Kp dependent radial diffusion (see Boscher *et al.*, 1998).

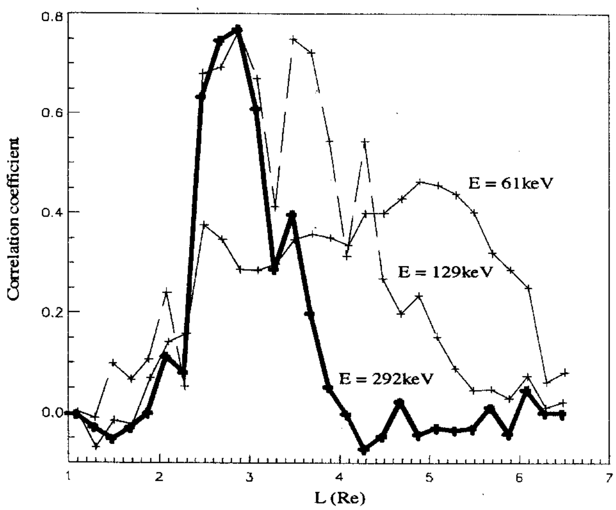

Fig. 1. Linear correlation versus L (McIlwain's parameter) between the fluxes measured by CRRES/MEB and those calculated by the Salammbô 2D code for 61keV (fine solid curve), 129keV (dashed curve) and 292keV (bold-faced solid curve) protons.

As a validation of this model, the figure 1 shows linear correlations versus L for three energies (61 keV, 129 keV and 292 keV). These coefficients were calculated using the validated measurements during the whole mission (from July 1990 to October 1991), more than 1000 orbits which means 1800 time series. At low L shells (typically L<2.5), CRRES/MEB measurements are contamined by high energy protons and electrons. At high L shells, calculations are performed with a quiet Olson-Pfitzer magnetic field model, which is not realistic during storms and substorms. Then, perturbations of the magnetic field due to substorms imply a variability in the measurements, not reproduced in the model. These two reasons explain why the correlation decreases at low and high L shells. At these low energies (61 keV), electric fields are important and the model is to be improved. The correlations are quite good (0.8) for the 129 and 292 keV energies in the ring current formation zone (between 3 and 4 Re) where the radial diffusion is acting. The good results of the code let us consider that the Kp index dependence of diffusion coefficients on storm time scales is going in a right way.

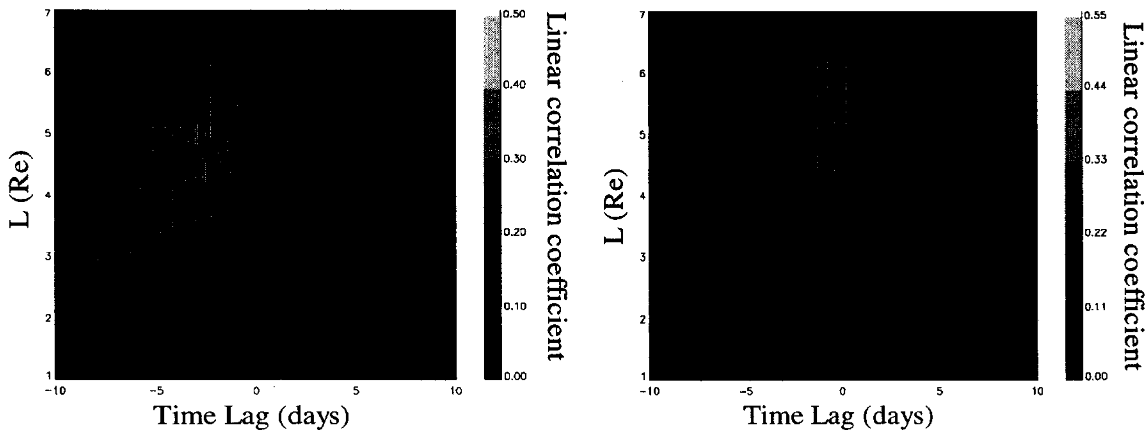

Fig. 2. Linear correlation (in grey scale) for 61 keV protons a) between the CRRES MEB measurements and the Kp index (left panel), and b) between the Salammbô 2D code results and the maximal Kp value in the preceding 24 hours (right panel).

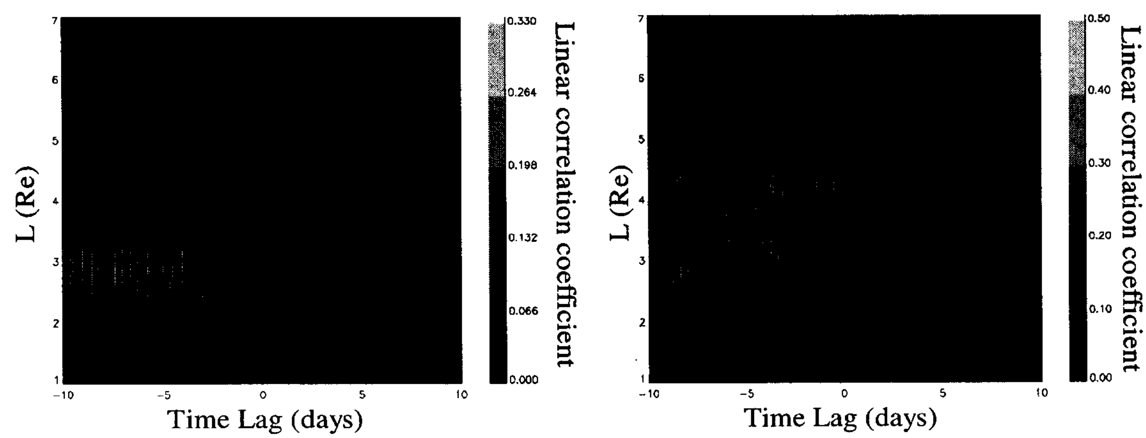

Fig. 3. Linear correlation (in grey scale) for 292keV protons between the Kp index and a) CRRES MEB measurements (left panel), and b) the Salammbô 2D code results (right panel).

To try to understand the dependence on this index on the ring current particles, figures 2 and 3 show comparisons of linear correlations between the Kp index and code results (figures 2b and 3b) on one hand, and the Kp index and CRRES MEB measurements (figures 2a and 3a) on the other hand, for two of the studied energies (61 keV and 292 keV). Those correlations are L dependent and consider the time lag between the Kp index and the flux variations.

First, when the energy increases, the time lag between Kp and the fluxes increases too, which can be explained by the radial transport delay and acceleration phenomena. This radial transport acceleration phenomena can also explain the lag of the maximal correlation towards lower L shell when the energy increases. On the other hand, when the energy increases, the correlation decreases for all L values. The flux variation time scale increasing for high energies (several days), it does not correspond to the three hourly scale of the Kp index. Finally, for proton energies more than 1 MeV, the correlations, not shown, are negligible for several reasons : the flux time scale extends from several days between 100 keV and 10 MeV, to several months or years between 10 MeV and 100 MeV; the physical phenomena (CRAND) responsible for the very high energy proton variations is not related to magnetic storms represented by the Kp variations. For those high energies, parameters related to the solar cycle variations are more appropriate.

Now, we can compare the Kp dependence in the code and in the measurements to verify if the use of the Kp index in the model is correct or not. First, the time delay of Kp on fluxes is similar in the code and in the measurements for 292 keV protons. For 61 keV protons, this time delay is shorter in the Salammbô code than in the measurements. But, if we introduce in the model the maximum value of the Kp index in the preceding 24 hours, related to the plasmasphere displacement (Carpenter and Anderson, 1992), this time delay becomes similar to that for the measurements of 61 keV protons, and the correlation level is more accurate. On the other hand, the maximum in correlation is spreading over a larger L zone for the code than for the measurements. That has been yet explained in the correlations between the code and the measurements (figure 1).

Last, in spite of that the Kp index is an input parameter of the code, the correlations obtained are not near the ideal value of one. The other physical phenomena introduced in the code are not Kp dependant and are important to determine the proton fluxes in the ring current. Anyway, relations are not linear (Boscher *et al.*, 1998). So, we must carefully interpret the correlation levels with the measurements. At last, radial diffusion is certainly the most storm dependent phenomena for this range of energies, but the trapping limit motion (energy dependant) considered here has to be improved.

CONCLUSION AND PROSPECTIVE

We have used the Salammbô-2D model, initially developed at ONERA-CERT/DESP to determine the storm influence on low energy equatorial protons, and to analyse the Kp index influence compared with in-flight satellite proton measurements. First, we can say that this Kp index is really a representative parameter with which to study the averaged storm influence on the radiation belt low energy proton fluxes. This study has principally shown that the correlation between Kp and fluxes is high as given in the code where the physical phenomenon acting here is the particle acceleration by radial transport diffusion. We can also detect for those energies an inertial effect in this phenomena greater than ten days if we use the Kp index variations. Such a model can reproduced storm variations in the proton radiation belt for a range of energy from several tens of keV to hundreds of keV just using the influence over several days of the Kp index in the radial transport diffusion acceleration. This code can easily evolve with the addition of new scientific knowledge.

To complete this study of storm influence on proton fluxes, we can extend those correlations with Kp for very low energy protons (up to several tens of keV) using the CRRES/LEPA detector to observe the injections on the night side of the magnetosphere. The problem is that those particles concern high L values on one hand, and very short time scales (several minutes) on the other hand, high L calculations being not good in CRRES data, and the time scales between Kp and those fluxes being very different, the correlations associated must not increase.

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